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STATIC LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A 0.07-SCALE MODEL OF A PROPOSED APOLLO SPACECRAFT AT MACH NUMBERS OF 1.57 TO 4.65

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON [redacted] September 1961

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL MEMORANDUM X-603

STATIC LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A 0.07-SCALE MODEL OF A PROPOSED APOLLO SPACECRAFT AT MACH NUMBERS OF 1.57 TO 4.65*

By James R. Morgan and Roger H. Fournier

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SUMMARY

An investigation has been conducted in the Langley Unitary Plan wind tunnel to determine the static aerodynamic characteristics of a 0.07-scale model of a proposed Apollo spacecraft. The configurations investigated consisted of the escape configuration with two lengths of escape tower support rods, the exit configuration (tower off), and the reentry configuration.

The results of this investigation have shown that force and moment nonlinearities are caused by the escape tower (long and short) and that, at angles of attack near 0°, this condition results in an unstable escape configuration at a Mach number of 1.57. The flow over the escape tower was found to contain oscillations that could have a significant effect on the structural design of the spacecraft. The reentry configuration is stable to an angle of attack of 45°, but an unstable break in the pitching-moment curve results in aerodynamic trim occurring at an angle of attack of 75.5°. The maximum lift-drag ratio of the reentry configuration was -0.71 and occurred at an angle of attack of about 54°.

INTRODUCTION

The National Aeronautics and Space Administration has initiated wind-tunnel investigations to determine the static longitudinal aerodynamic characteristics of a proposed Apollo spacecraft. As part of this program, tests were conducted in the Langley Unitary Plan wind tunnel on a 0.07-scale model of the spacecraft. Longitudinal aerodynamic characteristics were determined for the exit configuration with and without escape systems over a Mach number range from 1.57 to 2.87

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and over an angle-of-attack range from about -4° to 18°. Two tower lengths were investigated for the exit model with escape system. The reentry configuration was tested at a Mach number of 4.65 over an angle-of-attack range from about 0° to 85°. Transonic results for this model are presented in reference 1. The results of this investigation are presented herein with a minimum of analysis.

COEFFICIENTS AND SYMBOLS

The data of this investigation are presented about the system of axes shown in figure 1. Moment coefficients are referred to a point located on the model center line 3.677 inches from the base of escape and exit models (fig. 2) and 3.140 inches from the heat shield of the reentry model. The coefficients and symbols are defined as follows:

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C_A axial-force coefficient, $\frac{\text{Axial force}}{qS}$

$C_{A_{\alpha=0}}$ axial-force coefficient at $\alpha = 0^{\circ}$

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

C_N normal-force coefficient, $\frac{\text{Normal force}}{qS}$

$C_{N_{\alpha}}$ slope of normal-force coefficient curve at $\alpha = 0^{\circ}$, per degree

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSd}$

$C_{m_{\alpha}}$ slope of pitching-moment coefficient curve at $\alpha = 0^{\circ}$, per degree

C_{m_0} pitching-moment coefficient at $\alpha = 0^{\circ}$

L/D lift-drag ratio

d maximum diameter, 10.920 in.

M Mach number

[redacted]

q	free-stream dynamic pressure, $0.7pM^2$, lb/sq ft
S	maximum cross-sectional area, 0.6504 sq ft
α	angle of attack referred to model center line
R	Reynolds number
p	free-stream static pressure, lb/sq ft
p_t	free-stream stagnation pressure, lb/sq in.
x,y,z	model axes
X_s,Z_s	stability axes

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MODEL AND APPARATUS

Details of the models tested are given in figure 2. Photographs of the models are presented in figure 3.

The model was tested with and without the escape system and in a reentry attitude. Two lengths of tower support rods were investigated for the model with the escape system and the models with the escape system attached are referred to as the long- and short-tower configurations. The model without the escape system is referred to as the exit configuration and the model in the reentry attitude is designated as the reentry configuration.

The three tower support rods of the escape system formed, in cross section, an equilateral triangle whose base was in the horizontal plane and on the lower side of the model. (See fig. 2.)

The tests were conducted in the Langley Unitary Plan wind tunnel. This tunnel is a variable-pressure, continuous, return-flow type with two test sections 4 feet square and approximately 7 feet in length. An asymmetric sliding block nozzle provides a means to vary the Mach number continuously from 1.57 to 2.87 in one test section and from 2.36 to 4.65 in the other test section.

Forces and moments acting on the model were measured by an internal strain-gage balance. The model support system consisted of a balance-model-sting combination attached to a remotely operated adjustable angle coupling connected to the tunnel central support system. Pressure measurements at the base of the model were made with a pressure-sensitive electrical pickup.

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TESTS

The escape and exit model configurations were tested through a Mach number range from 1.57 to 2.87 and an angle-of-attack range from about -4° to 18°. The reentry configuration was tested at a Mach number of 4.65 over an angle-of-attack range from about 0° to 85°. Test conditions are summarized in the following table:

M	p_t, lb/sq in.	q, lb/sq ft	R/ft
1.57	13.0	797	3.51×10^{6}
2.16	16.5	772	3.33
2.87	23.4	645	3.28
4.65	84.4	528	4.59

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CORRECTIONS AND ACCURACY

All angles of attack have been adjusted for flow angularity and structural deflection of the sting-balance combination under load. The axial-force and drag coefficients presented are the total values of the forces measured by the balance and therefore have not been adjusted in any way for the pressure acting at the base of the model. The maximum deviation of the local Mach number in the region of the tunnel occupied by the model is ±0.015. The estimated accuracies of the angles of attack and the coefficients, based on the balance calibration and the repeatability of the data, are within the following limits:

α . . . . ±0.10
C_N . . . . ±0.01
C_A . . . . ±0.01
C_m . . . . ±0.002

PRESENTATION OF RESULTS

The results of an investigation of the static stability characteristics of a 0.07-scale model of a proposed Apollo spacecraft in the escape and exit configurations at Mach numbers of 1.57, 2.16, and 2.87 and in the reentry configuration at a Mach number of 4.65 are presented in the following figures:

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DISCUSSION

The results of this investigation were not analyzed extensively; however, it is pertinent to indicate briefly some of the significant aerodynamic effects shown by these data.

The results (figs. 5 and 6) show that the escape configurations (long and short tower) are statically stable near an angle of attack of 0° at the test moment center except for a Mach number of 1.57. The instability of the escape configuration at $M = 1.57$ near 0° exists over a small angle-of-attack range. These effects at a Mach number of 1.57 are a result of the nonlinear character of the data.

A comparison of the results for the long tower with those for the short tower shows that the pitching-moment characteristics and, to a lesser degree, the normal-force characteristics are more nonlinear with the long tower than with the short tower. The nonlinearities involve a general destabilizing break in pitching moment at all Mach numbers at an angle of attack greater than 7°. In addition, at the lowest test Mach number (1.57) and at an angle of attack of about 0°, nonlinear breaks in the pitching-moment and normal-force curves develop with both the long and short towers. The schlieren photographs (fig. 4) show a very complicated flow field which contains extensive regions of separated flow enveloping the spacecraft and originating from the nozzles at the base of the escape rocket. With such flow it is not surprising to find nonlinear static force and moment results. To determine whether the flow over the system contained any oscillation, high-speed schlieren motion pictures were taken. The film indicated that flow oscillations existed not only for the long tower for which the largest nonlinearity of static force and moment results developed but also for the short-tower configuration. Flow oscillation was most severe at angles of attack near 0° for both tower lengths. It would appear then that a serious structural design problem may exist. Furthermore, an aerodynamic problem may also exist because of the nonlinear characteristics of the force and moment results.

The results for the exit configuration (tower off) indicate (fig. 7) linear force and moment characteristics throughout the angle-of-attack range and a statically stable configuration with a positive normal-force curve slope. It is to be noted that discrete values of pitching-moment coefficients exist $\left(C_{m_O} \neq 0\right)$ at an angle of attack of 0° at Mach numbers of 1.57 and 2.87. Because of the symmetry of this configuration, $C_{m_O} = 0$ would be expected. It appears, therefore, that some surface irregularity of the model is introducing an asymmetry of normal-force and pitching-moment values at Mach numbers of 1.57 and 2.87.

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The reentry configuration which was tested only at a Mach number of 4.65 is statically stable (fig. 8) and has a positive normal-force curve slope; however, because of the high values of axial-force coefficient, the reentry configuration has a negative lift-curve slope (fig. 8(b)). The maximum lift coefficient occurs at an angle of attack of about 35°. The maximum lift-drag ratio is about -0.71 and occurs at an angle of attack of about 54°. It should be noted that, to achieve a positive value of lift-drag ratio, flight at negative angles of attack would be required.

An unstable break develops in the pitching-moment curve for the reentry configuration at angles of attack greater than about 40°. At angles of attack greater than about 45° the model is unstable and a trim condition exists at an angle of attack of 75.5°. It is again to be noted that $C_{m_O} \neq 0$ as would be expected. As mentioned before, this result is probably due to some surface irregularity of the model.

CONCLUDING REMARKS

The results of this investigation have shown that force and moment nonlinearities are caused by the escape tower (long and short) and that at angles of attack around 0° this condition results in an unstable escape configuration at a Mach number of 1.57. The flow over the escape tower was found to contain oscillations that could have a significant effect on the structural design of the spacecraft. The reentry configuration is stable to an angle of attack of about 45°, but an unstable break in the pitching-moment curve results in aerodynamic trim occurring at an angle of attack of 75.5°. The maximum lift-drag ratio of the reentry configuration was -0.71 and occurred at an angle of attack of about 54°.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., August 3, 1961.

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REFERENCE

1. Pearson, Albin O.: Wind-Tunnel Investigation of the Static Longitudinal Aerodynamic Characteristics of Models of Reentry and Atmospheric-Abort Configurations of a Proposed Apollo Spacecraft at Mach Numbers From 0.30 to 1.20. NASA TM X-604, 1961.

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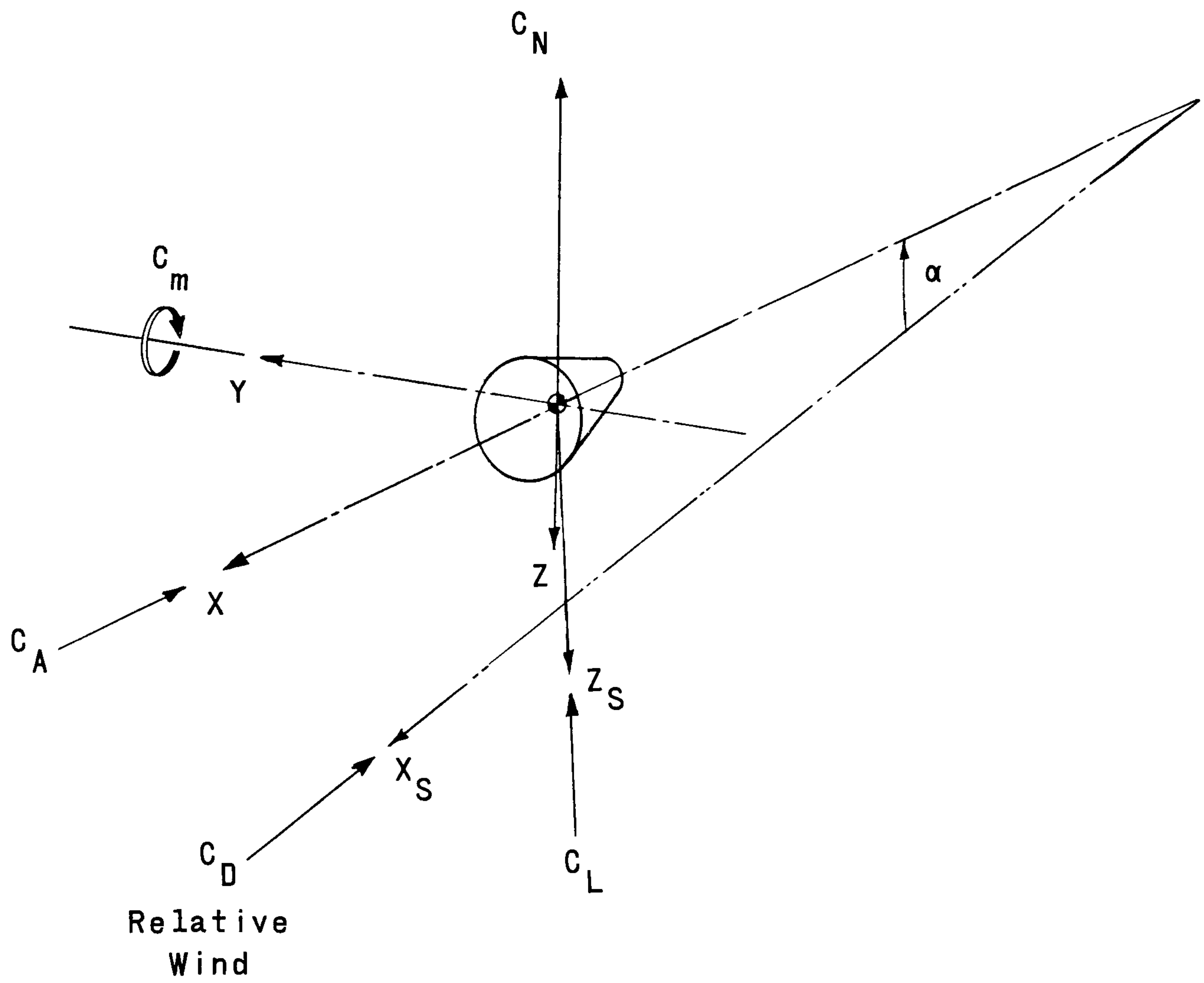
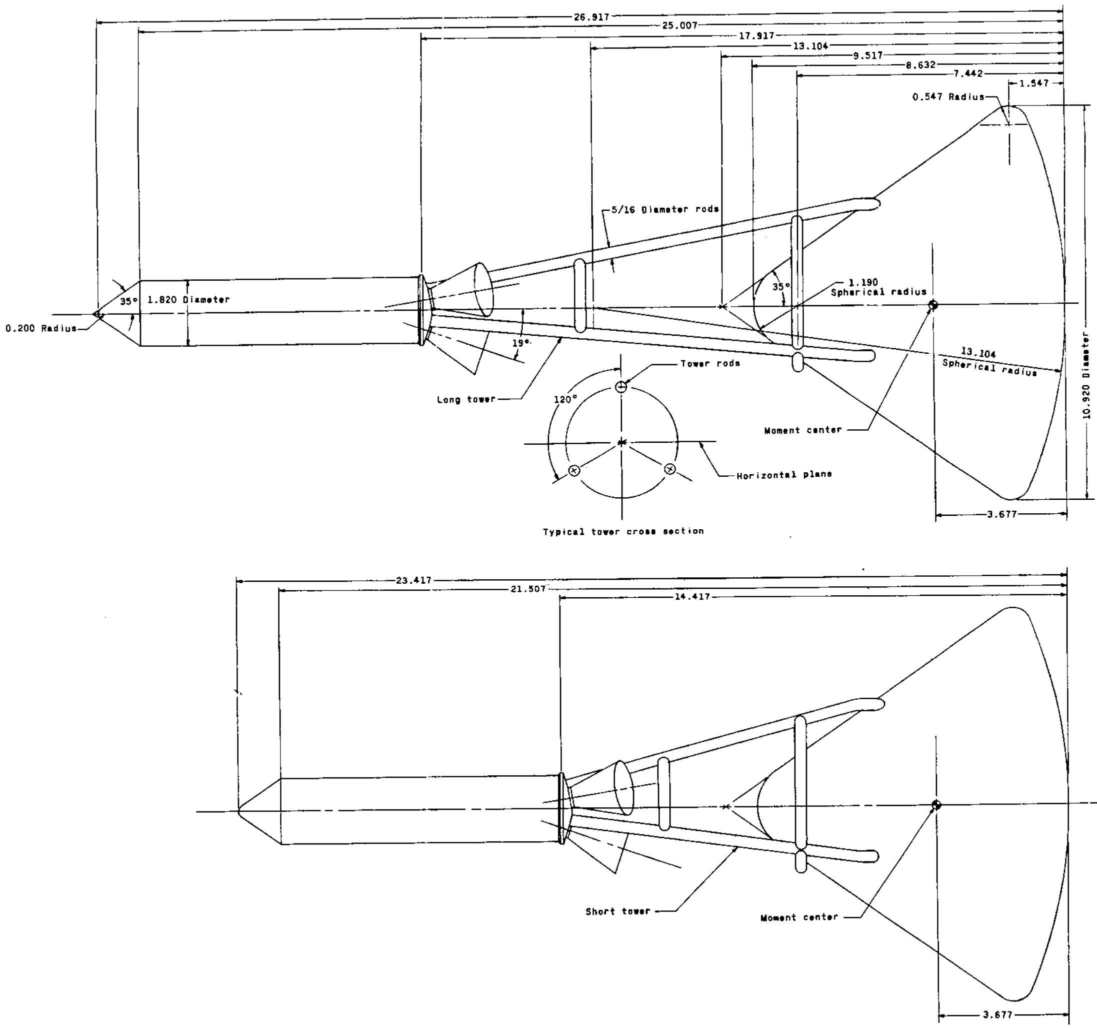


Figure 1.- System of axes. Arrows indicate positive values. (Reentry configuration shown.)



(a) Escape configuration with long and short tower.

Figure 2.- Details of the models tested. Dimensions are in inches unless otherwise noted.

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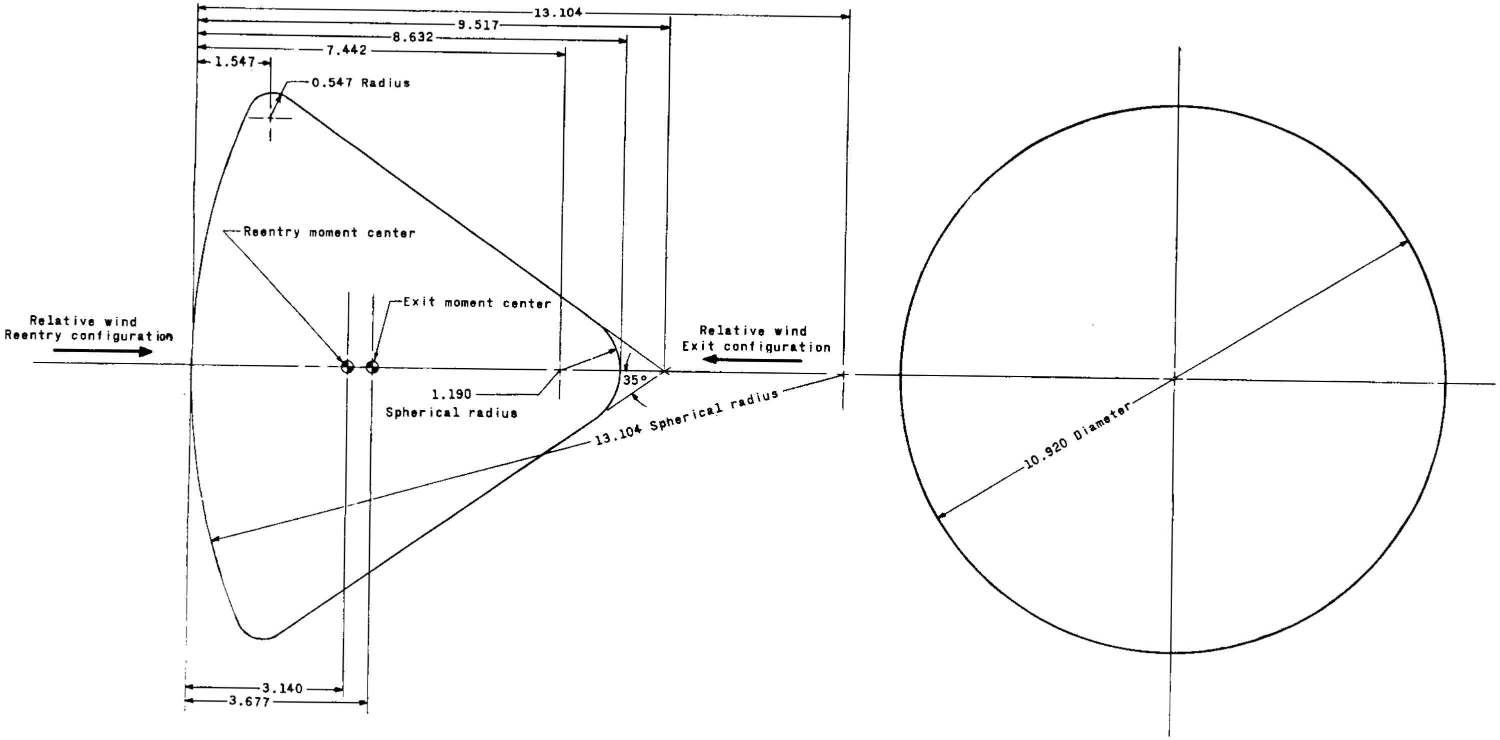

(b) Reentry and exit configuration.

Figure 2.- Concluded.

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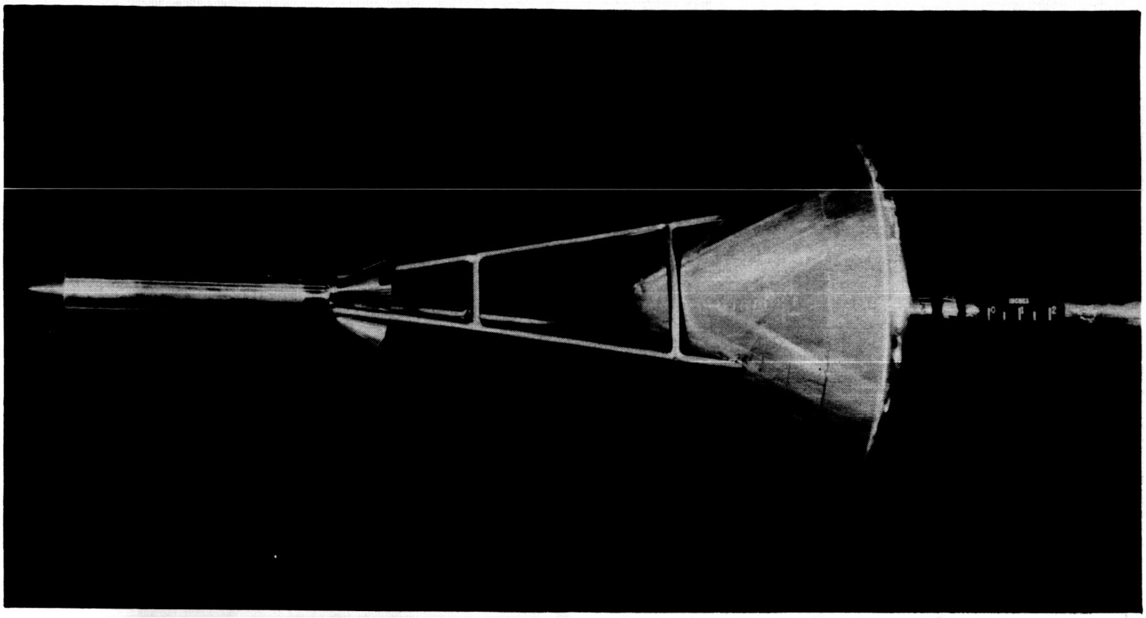
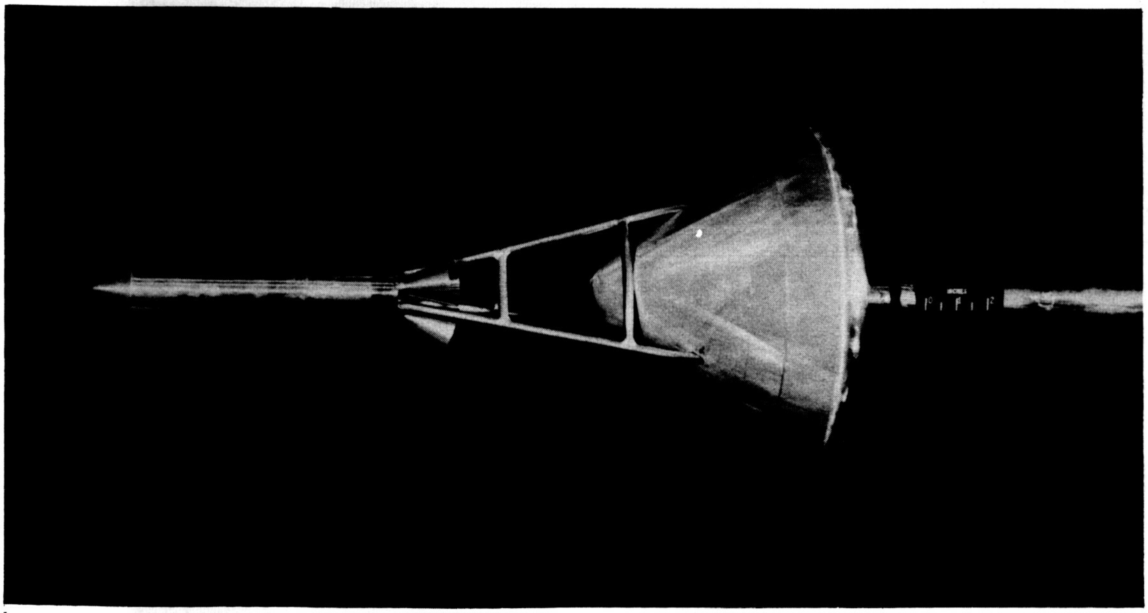


Escape configuration; long tower

L-61-4886



Escape configuration; short tower

Figure 3.- Typical model photographs. L-61-4887

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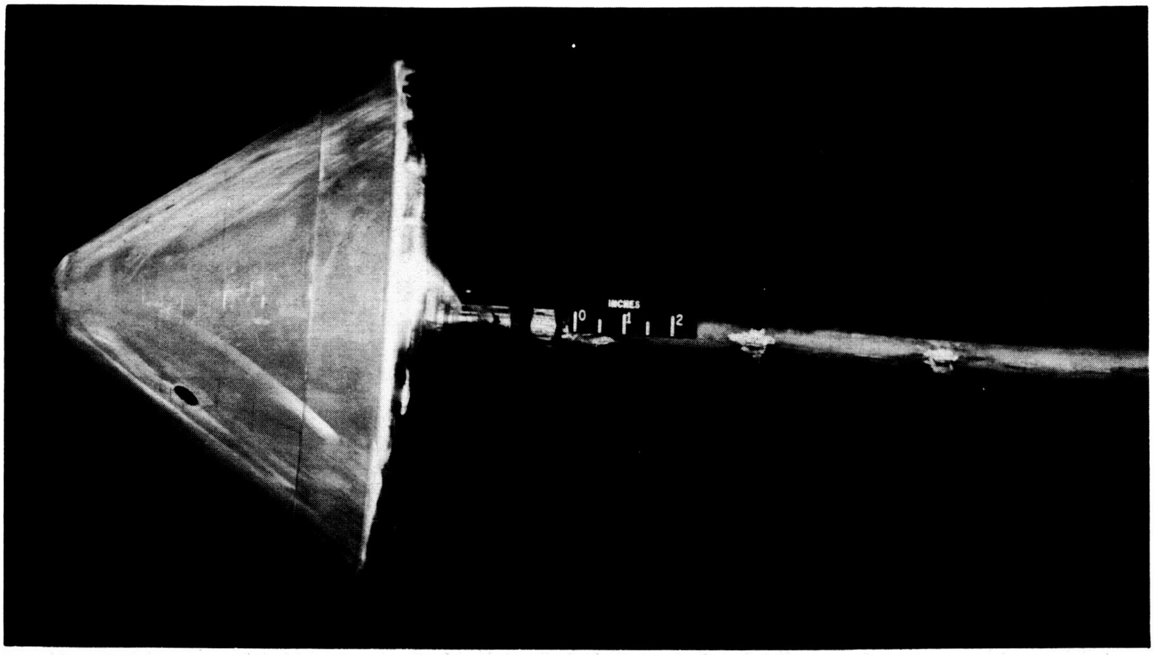

Exit configuration

L-61-4884

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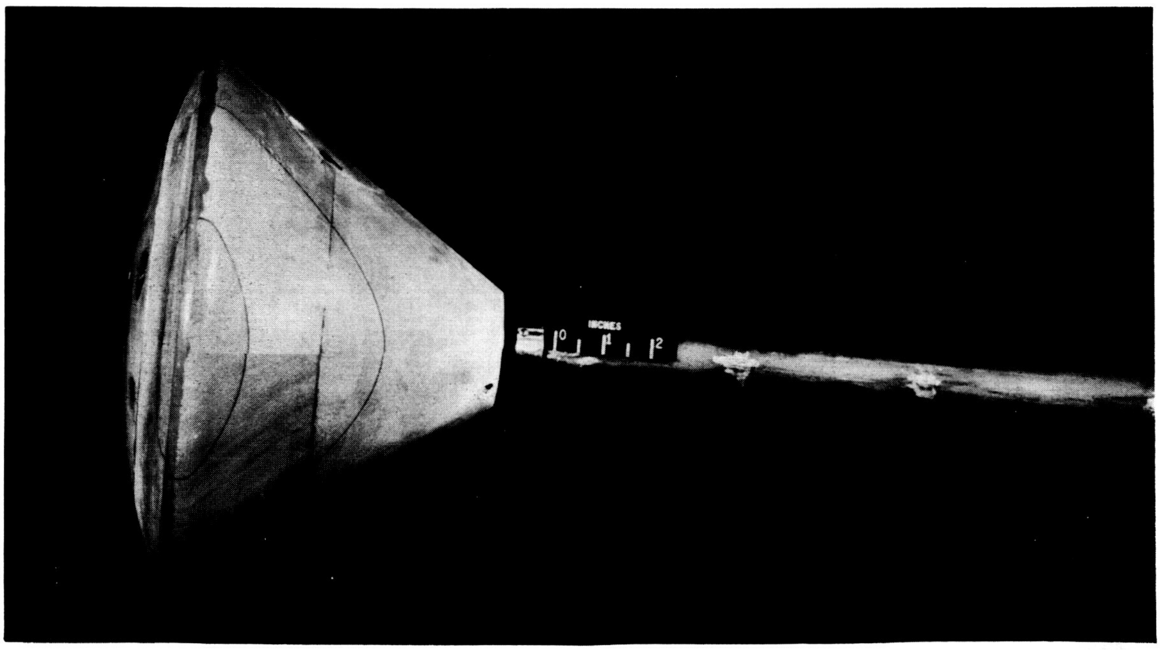

Reentry configuration

Figure 3.- Concluded. L-61-4882

[redacted]

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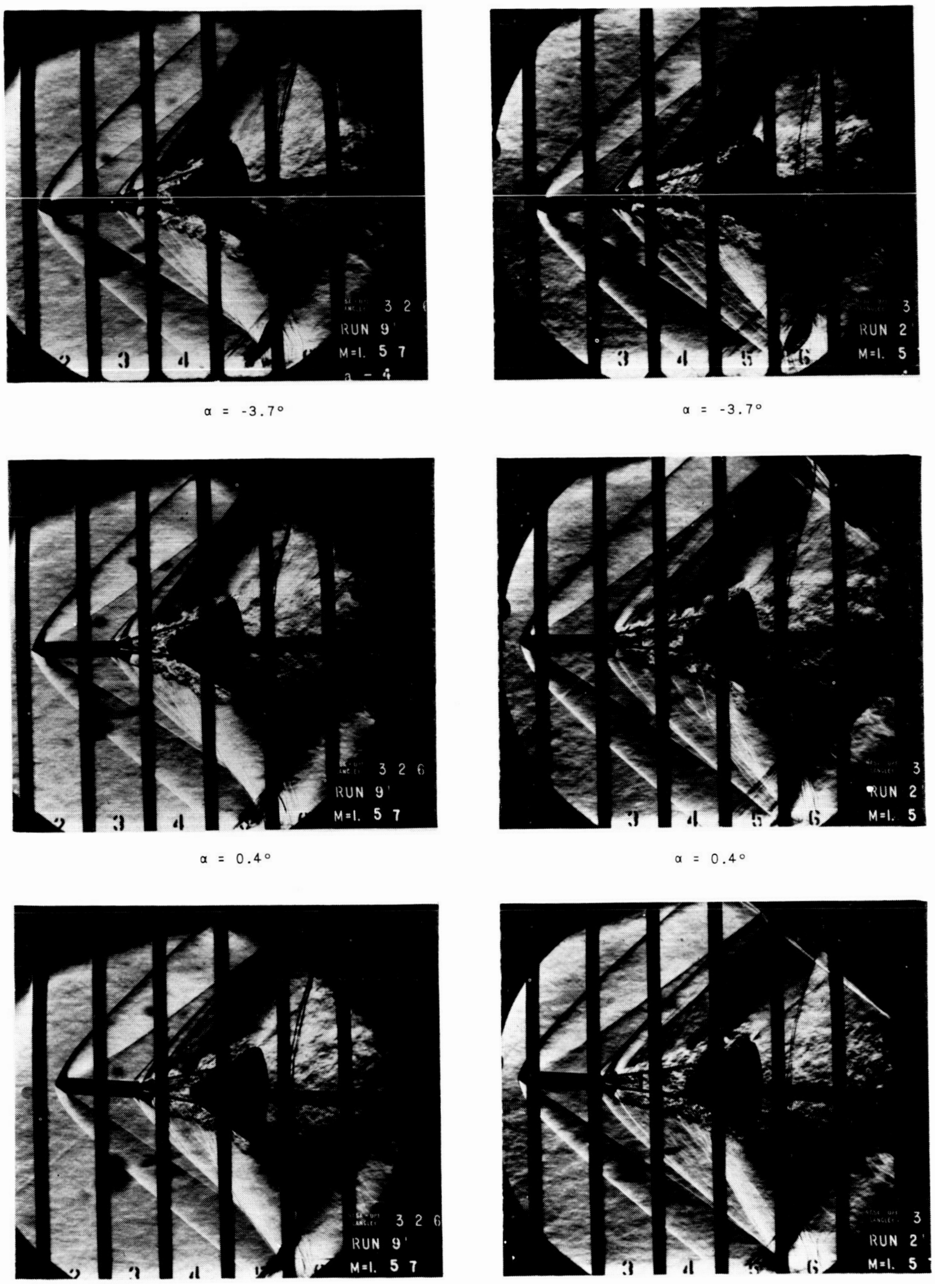

α = -3.7°　　α = -3.7°

α = 0.4°　　α = 0.4°

α = 4.5°　　α = 4.6°

M = 1.57

Short tower　　Long tower

(a) Escape configuration. L-61-5056

Figure 4.- Typical schlieren photographs.

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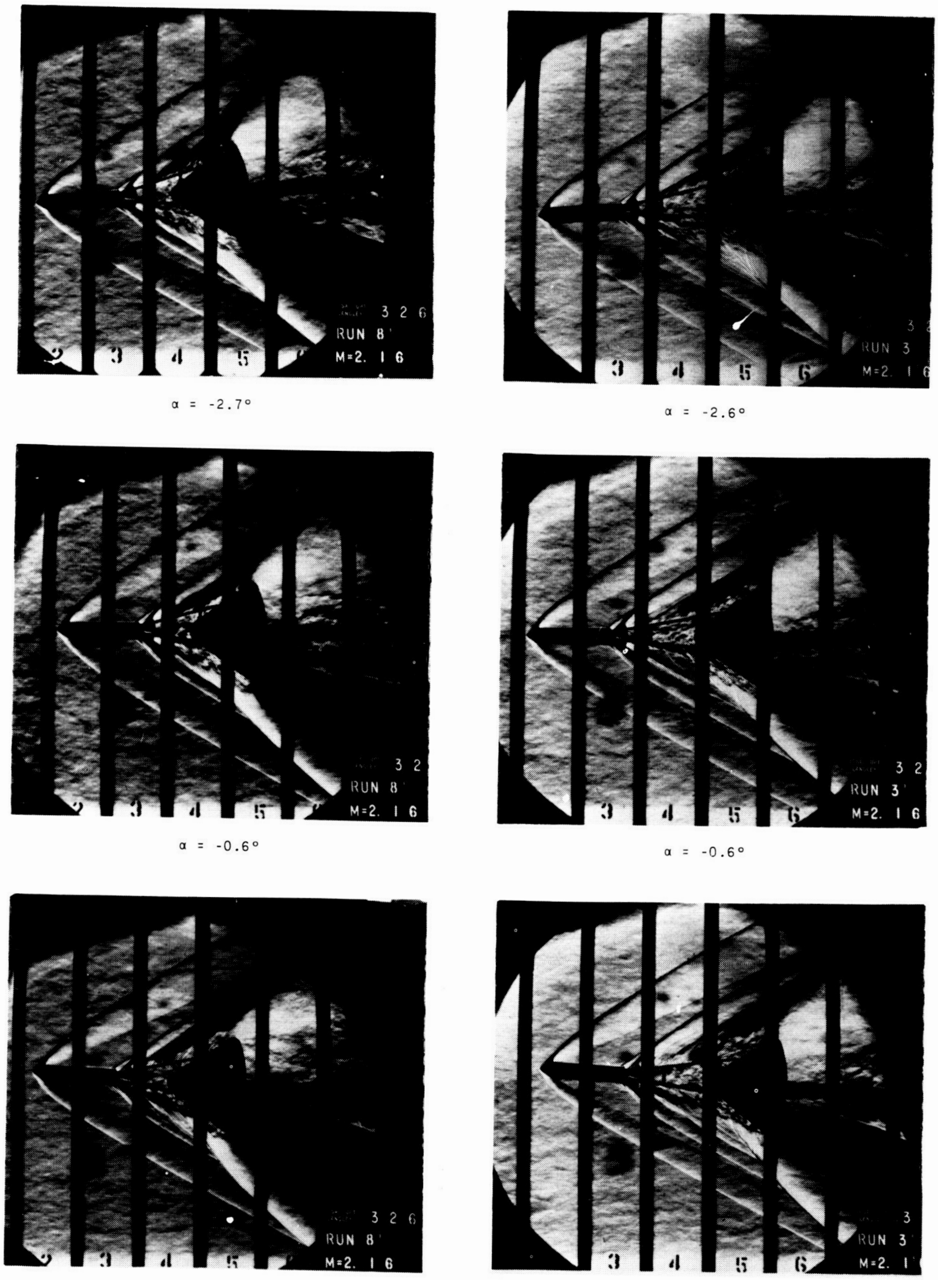

α = -2.7° α = -2.6°

α = -0.6° α = -0.6°

α = 3.5° α = 3.5°

Short tower M = 2.16 Long tower

(a) Continued. L-61-5057

Figure 4.- Continued.

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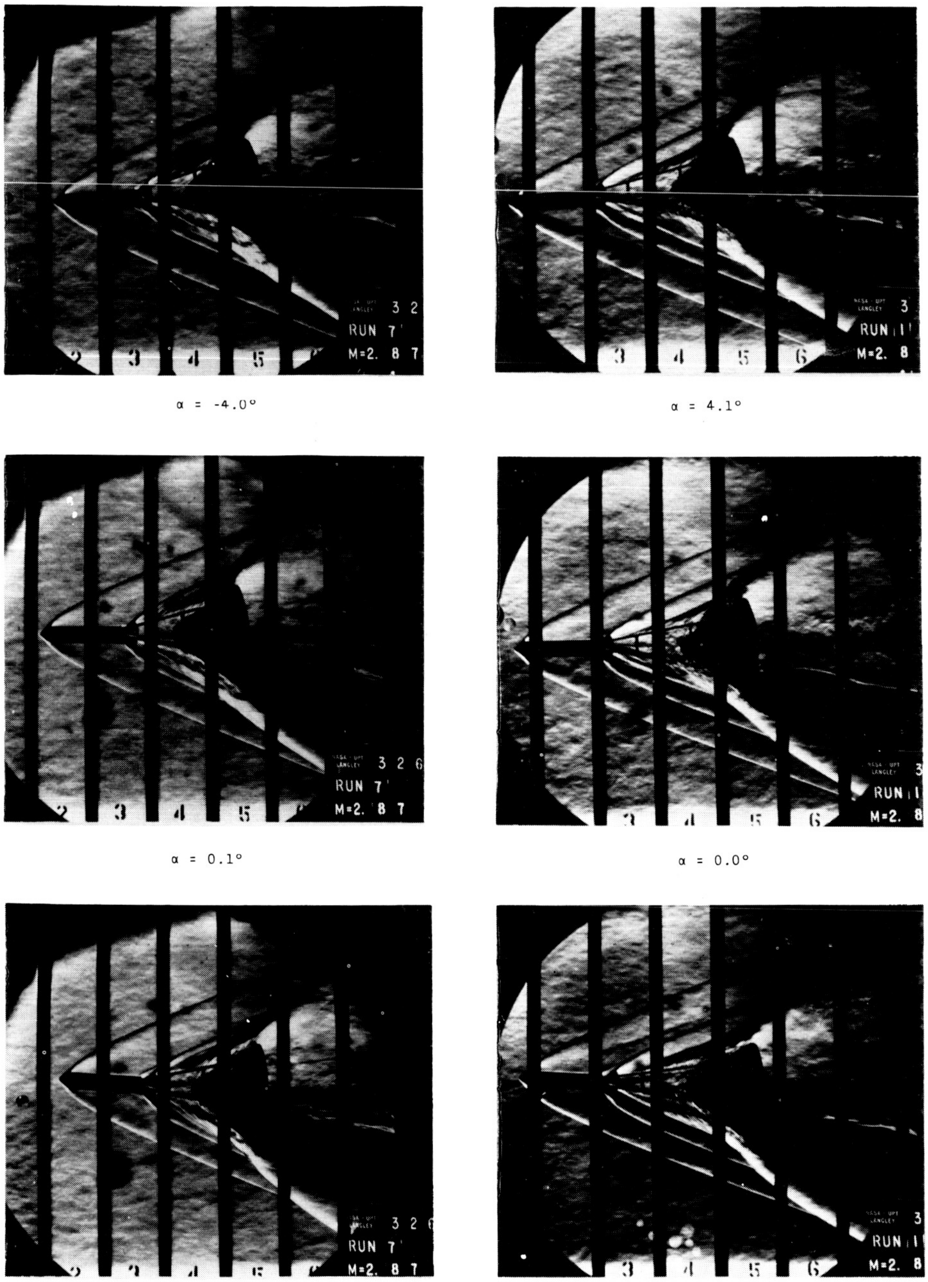

α = -4.0°

α = 4.1°

α = 0.1°

α = 0.0°

α = 4.2°

α = -4.1°

M = 2.87

Short tower

Long tower

(a) Concluded.

L-61-5058

Figure 4.- Continued.

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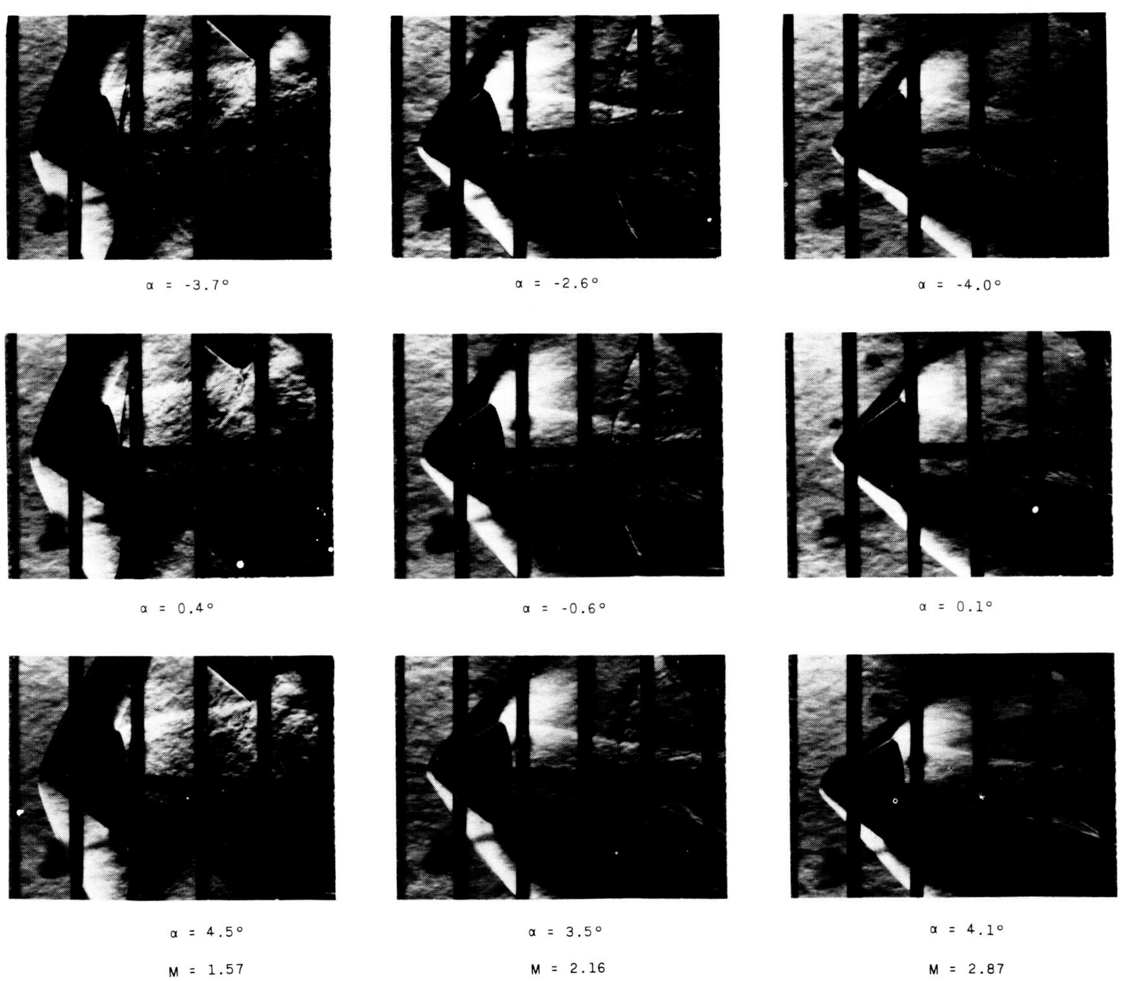

(b) Exit configuration. L-61-5059

Figure 4.- Continued.

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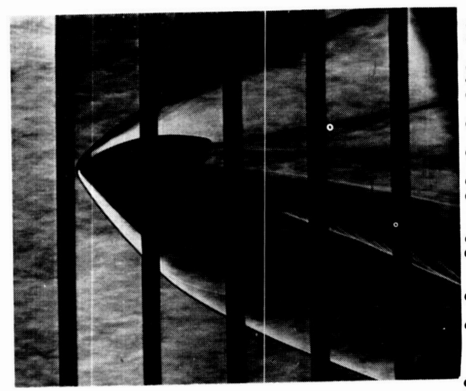
α = -0.8°

α = 19.0°

α = 41.0°

α = 61.2°



α = 81.4°

L-61-5060

(c) Reentry configuration. M = 4.65.

Figure 4.- Concluded.

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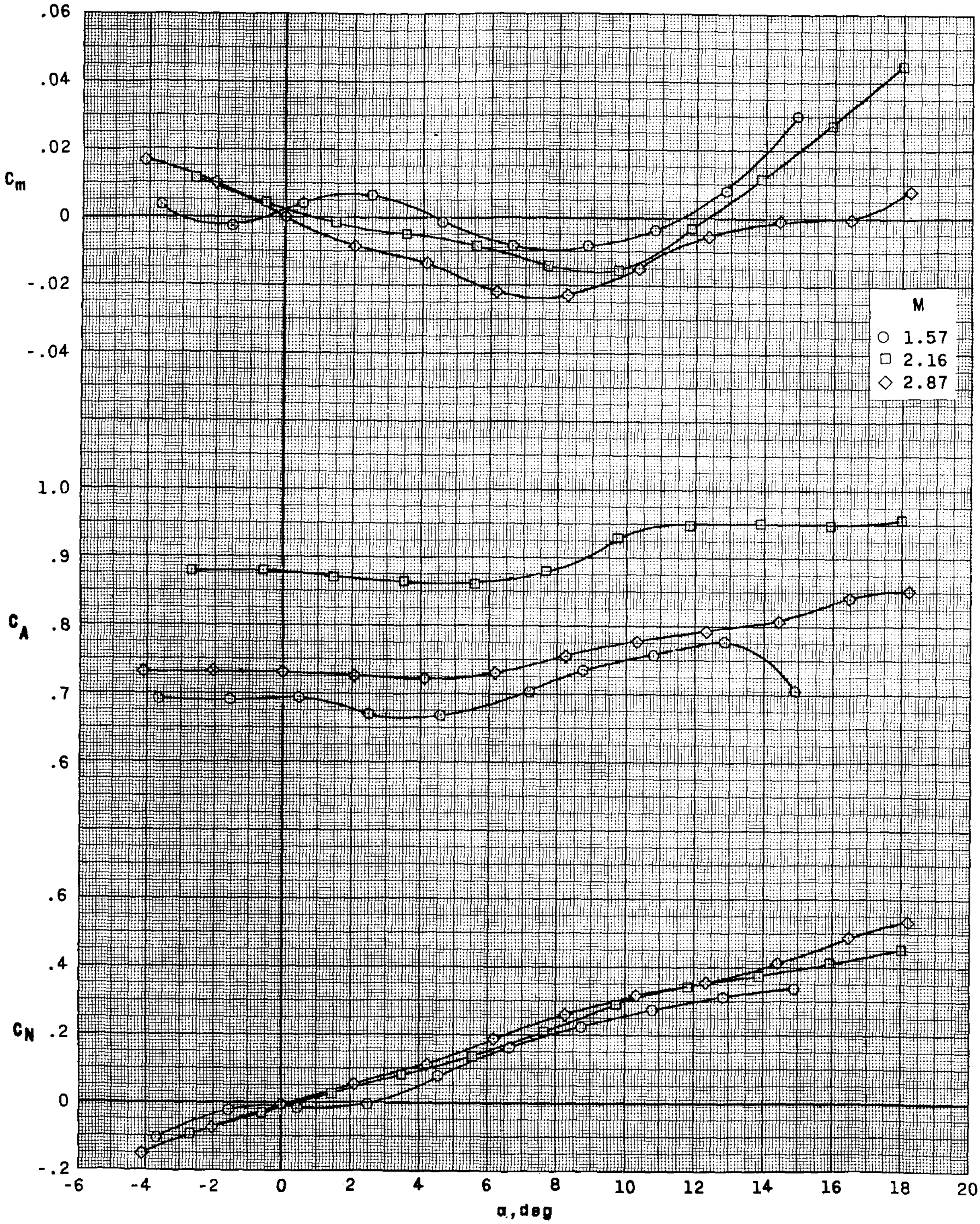

Figure 5.- Longitudinal aerodynamic characteristics of the escape configuration with long tower.

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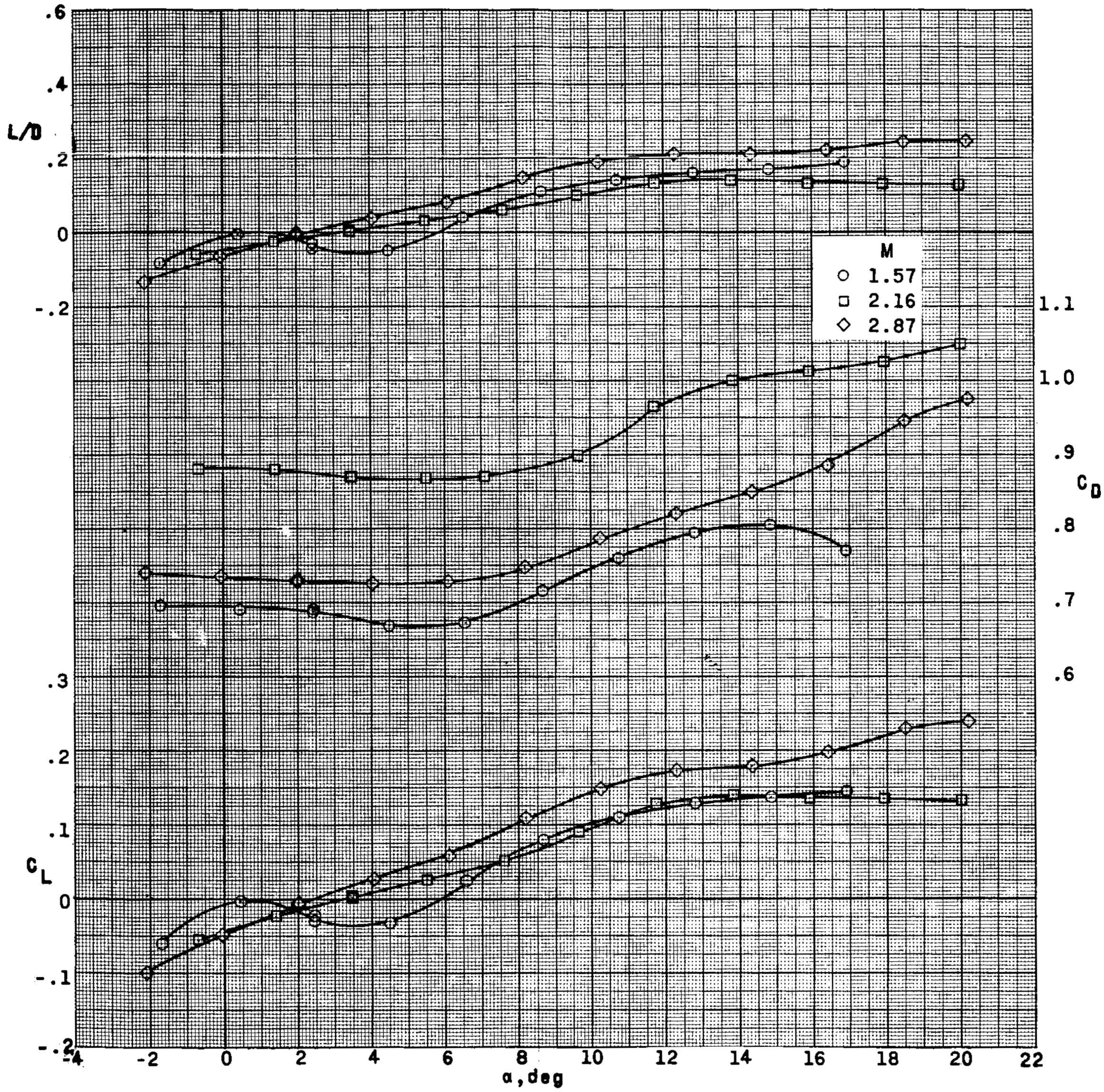

Figure 5.- Concluded.

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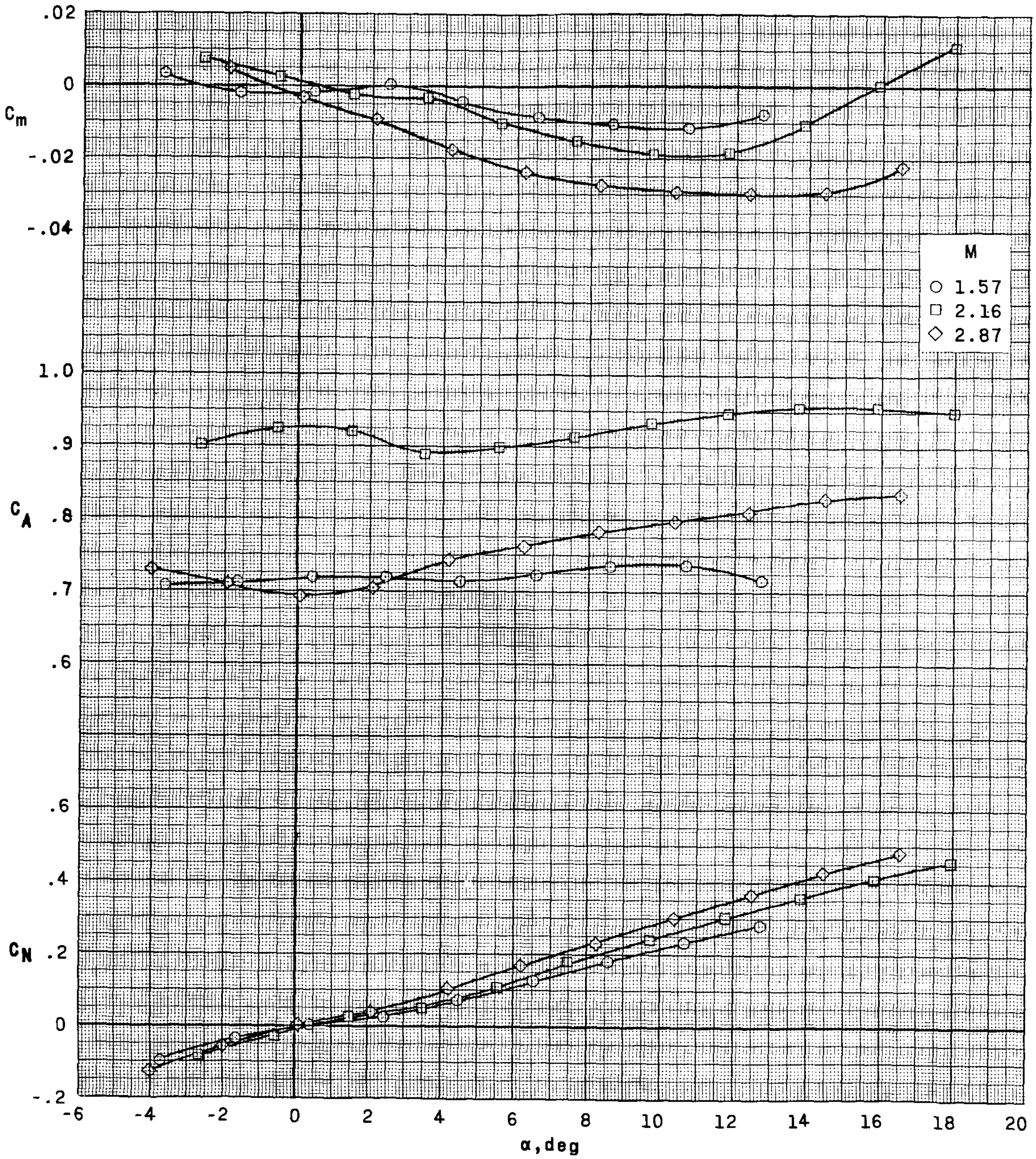

Figure 6.- Longitudinal aerodynamic characteristics of the escape configuration with short tower.

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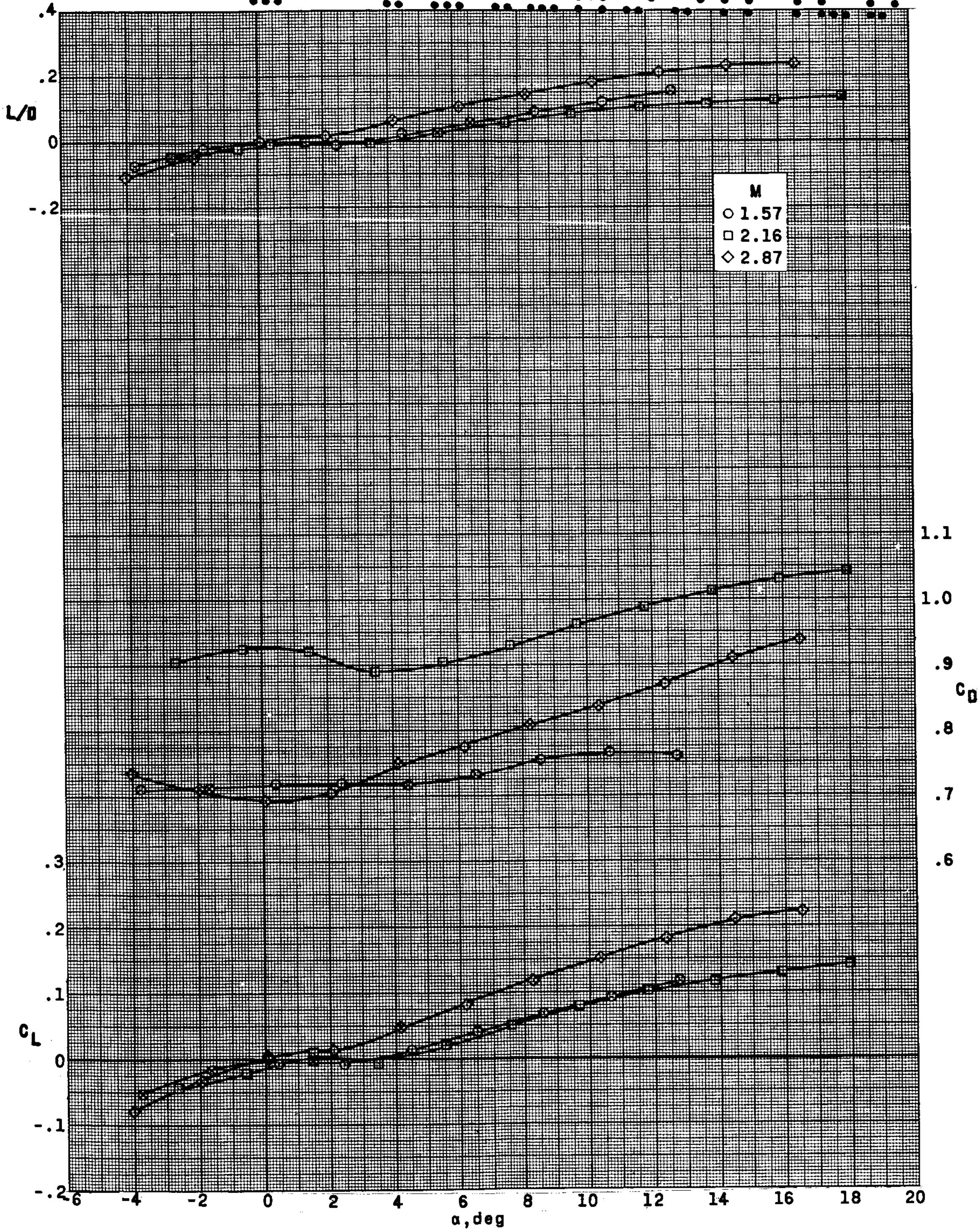

Figure 6.- Concluded.

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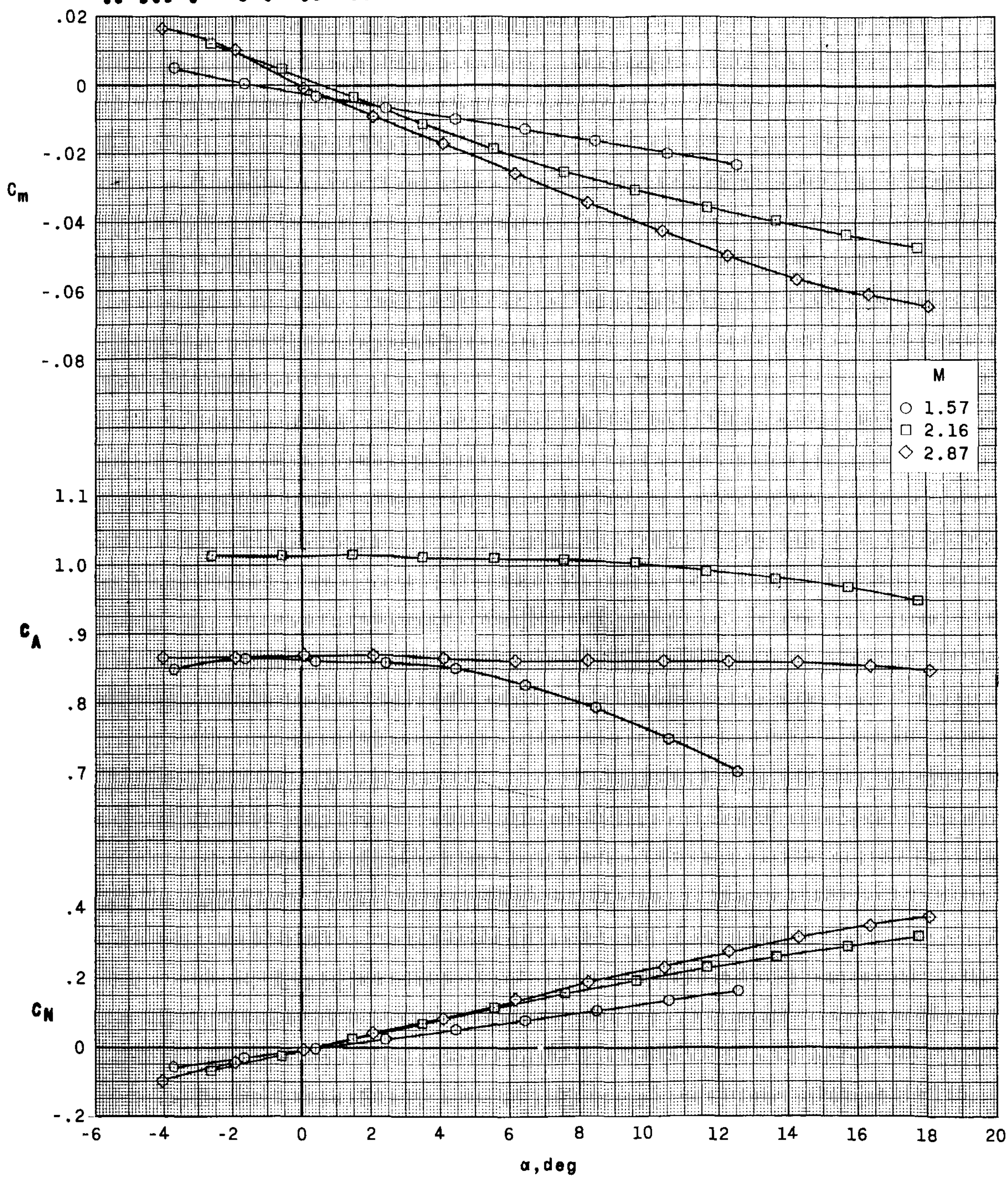

Figure 7.- Longitudinal aerodynamic characteristics of the exit configuration.

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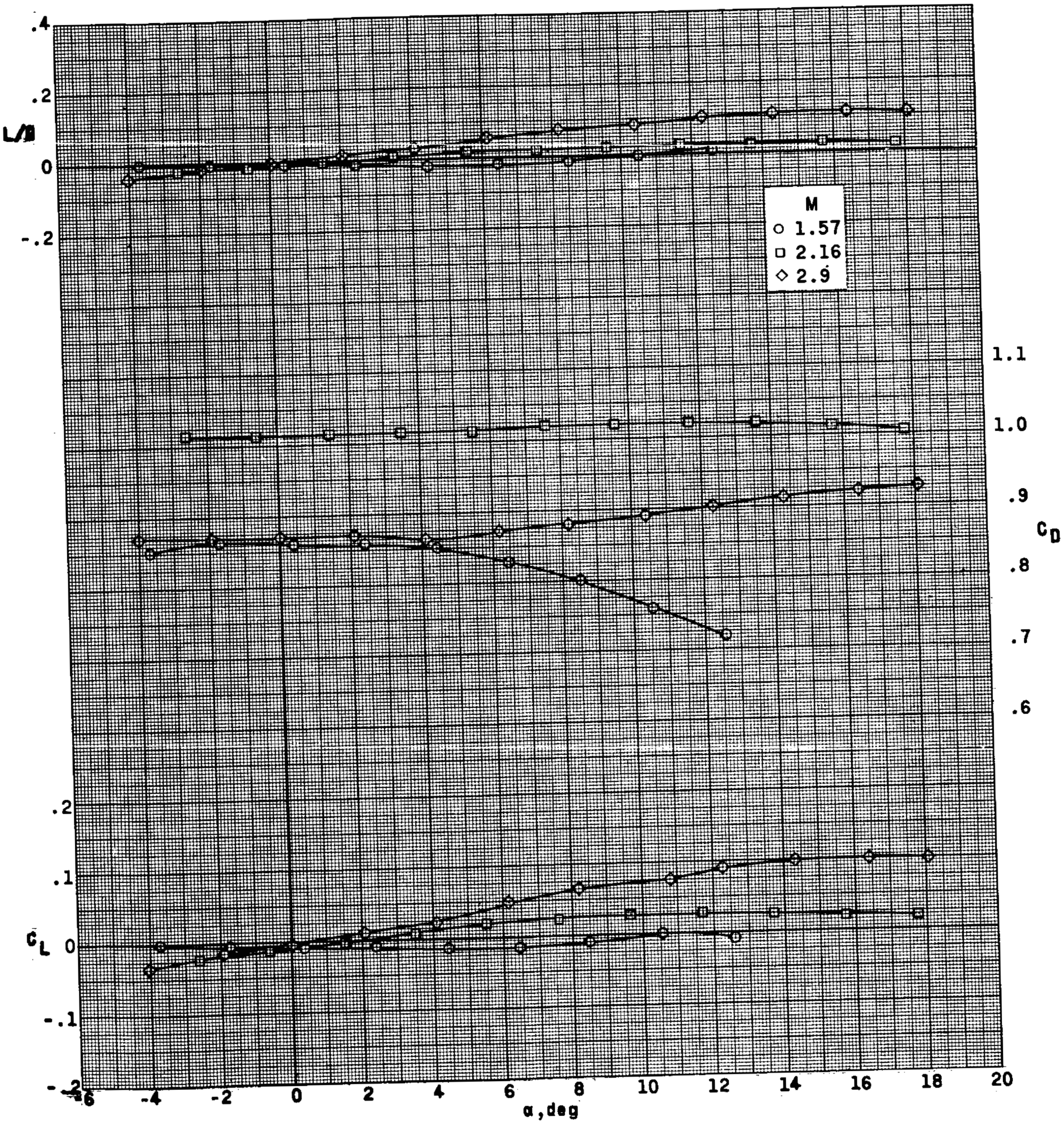

Figure 7.- Concluded.

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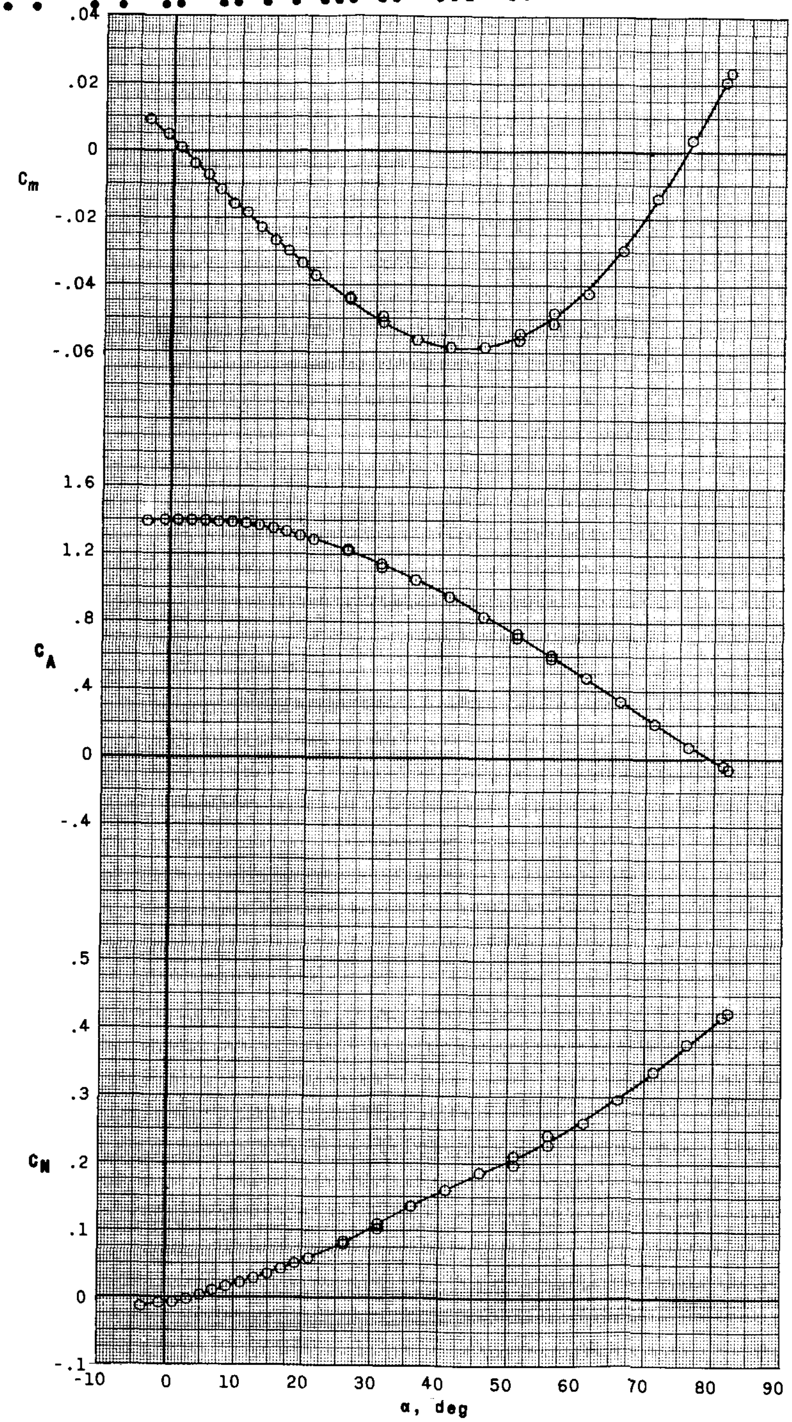

Figure 8.- Longitudinal aerodynamic characteristics of the reentry configuration. M = 4.65.

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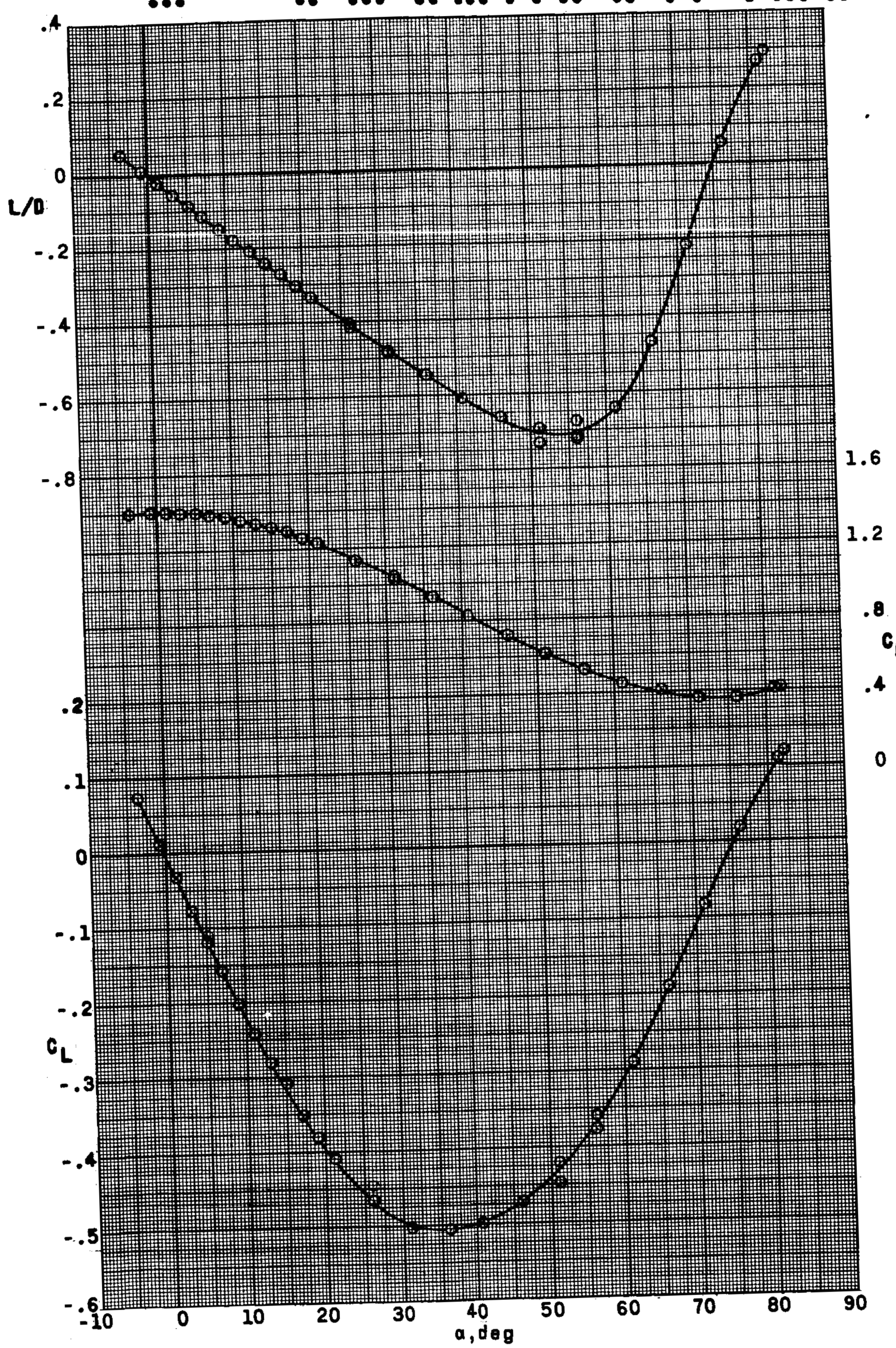

Figure 8.- Concluded.

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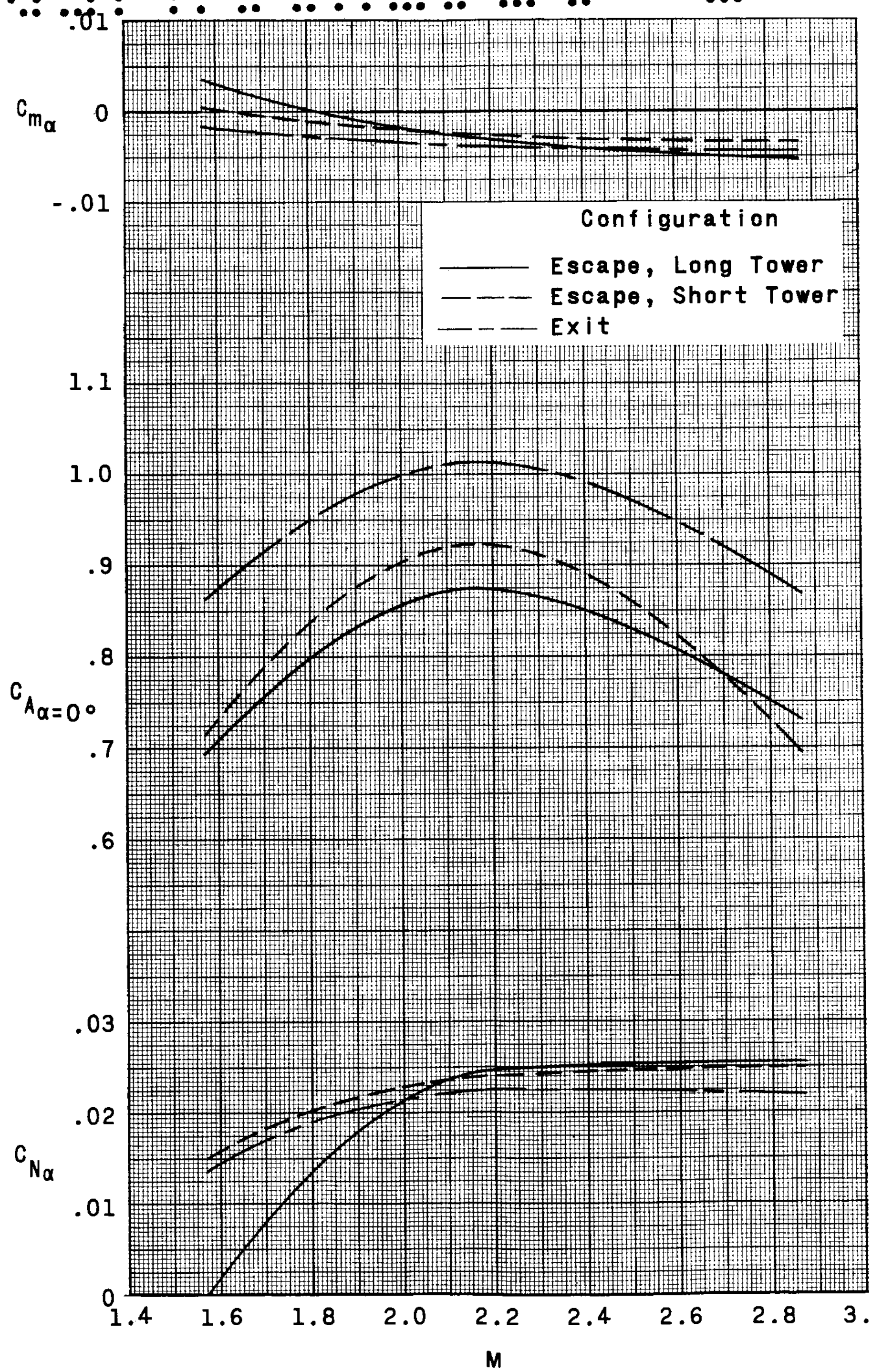

Figure 9.- Summary of the longitudinal aerodynamic characteristics of the escape and exit configurations.

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